



Green Propulsion Technologies for Advanced Air Transports

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Green Propulsion Technologies for Advanced Air Transports

- Nearly a century of aeronautics research; more than 70 years at NASA Glenn Research Center
- Global economic importance of aviation
- NASA Aeronautics Mission and subsonic research
- Why hybrid-electric propulsion?
- A NASA perspective on enabling hybrid-electric propulsion for commercial transport aircraft
- NASA technologies for hybrid-electric propulsion
- Looking to the future

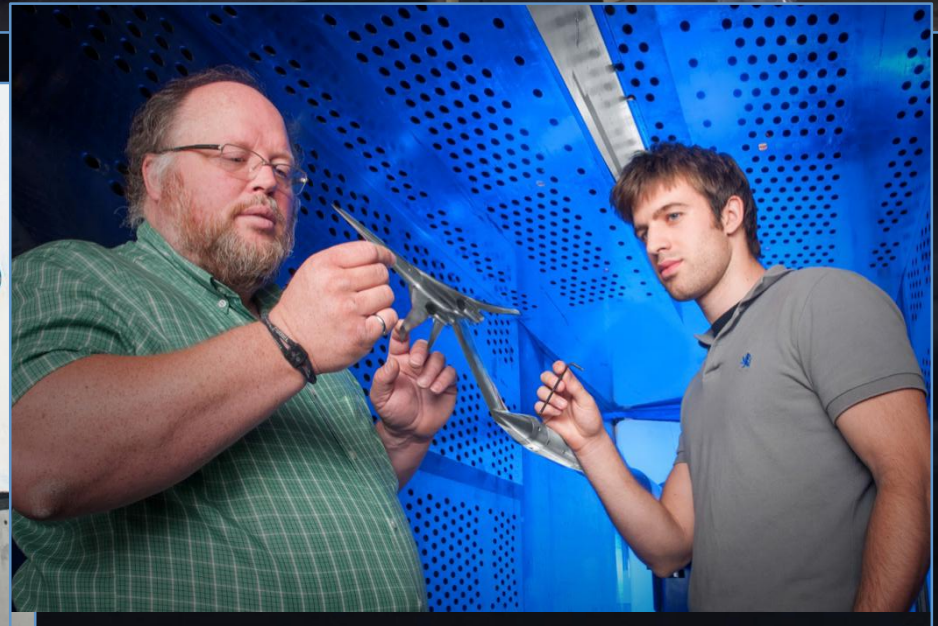
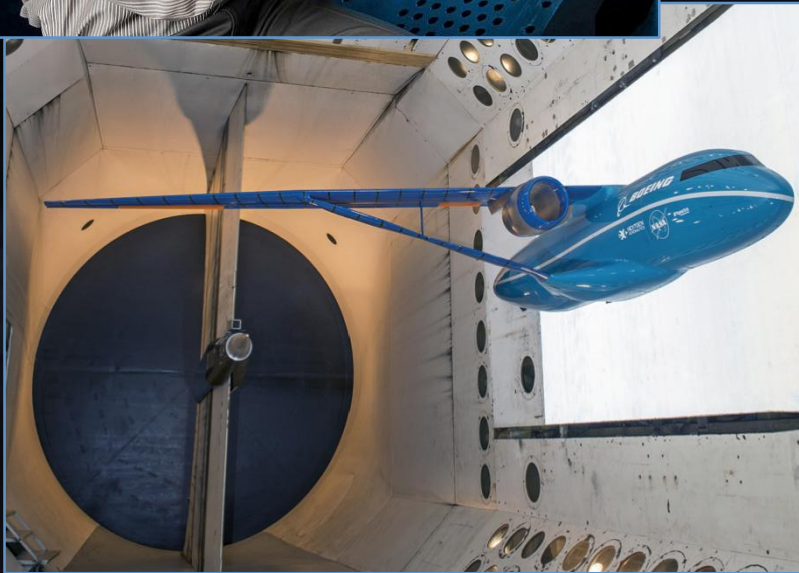
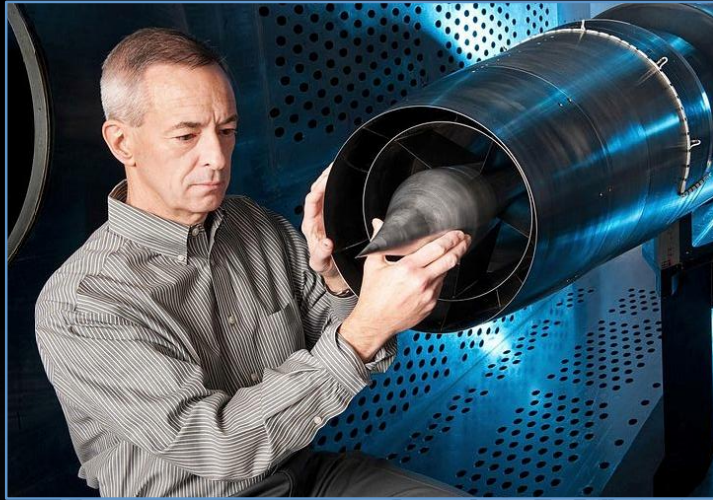


We've come so far, yet we have so far to go.





NASA Aero Centers: Conducting research to make aviation greener

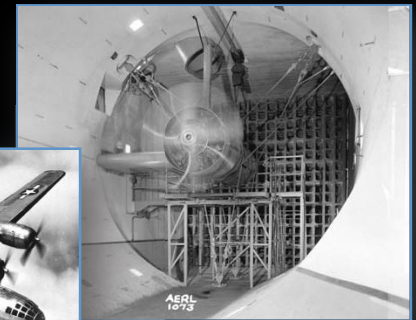




Glenn: More than 70 years of Aeropropulsion history/accomplishments

1940s: Engine research begins

- Turbocharging of reciprocating engines enabled high altitude flight of B-29 Superfortress.
- America's first turbojet tested at Glenn's Lewis Field. Hands-on experience with early jet engines begins.
- Icing Research Tunnel built at Lewis Field—significantly enhanced aviation safety advancing icing technology...the longest operating and second largest refrigerated wind tunnel in the world.

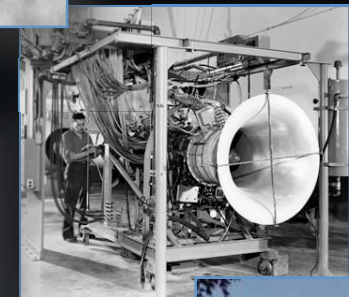
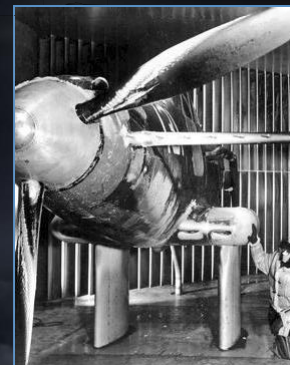


1950s: Advanced air-breathing propulsion SOA

- Pioneered transonic compressors, cooled turbines, and stable afterburning.

1960s: Developed technologies for noise and emissions reductions

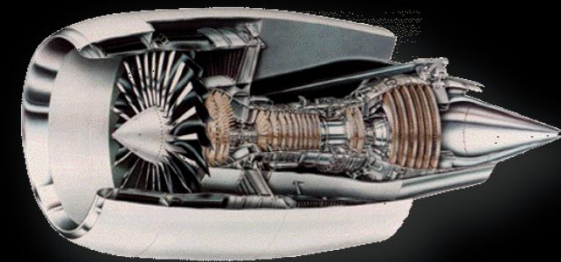
- 10 dB quieter and 60% cleaner—developed unique expertise in wind turbine design for power generation.





Glenn: More than 70 years of Aeropropulsion history/accomplishments

1970s: Technologies for high-efficiency turbofan engines



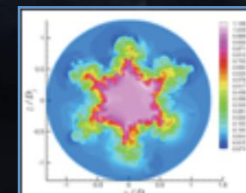
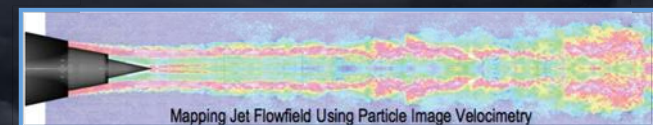
1980s: Technologies for ultra-efficient high-speed turboprops

- Potential to achieve 35% reduction in fuel consumption – Advanced Turbo Prop (ATP) program



1990s: Chevron nozzles—from idea to deployment

- Basic studies on jet mixing suggest that tabs can enhance jet mixing, with the potential to reduce noise
- Computational and experimental research to develop understanding of the governing fluid mechanics
- Team effort involving industry, universities, and NASA

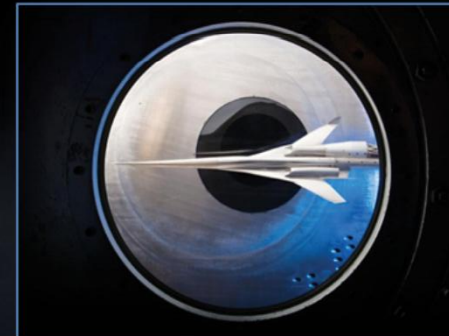




Glenn: More than 70 years of Aeropropulsion history/accomplishments

2000s: Green aviation—from idea to deployment

- Ground-test evaluation in engine test stands
- Flight evaluation in relevant environments
- Twin Annular Premixing Swirler (TAPS) Combustor
~50% reduction in nitrogen oxide emissions



2010s: Low boom, biofuels, and icing

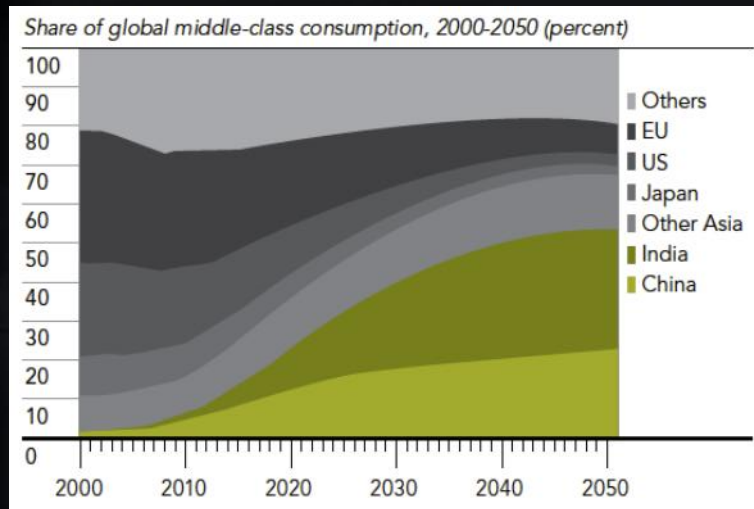
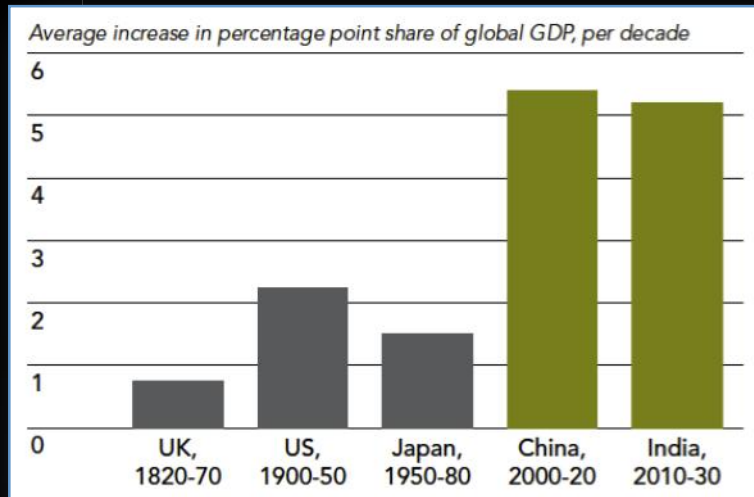
- Commercial N+2 supersonic aircraft wind tunnel research proves viable low-boom design.
- NASA Glenn Propulsion Systems Laboratory achieves first engine ice crystal icing rollback at simulated cruise altitude.
- NASA Glenn-led biofuels research flight campaigns further green aviation research.
- European Airbus-led High Altitude Ice Crystals/High Ice Water Content field campaign in Darwin, Australia.





What do emerging global trends reveal?

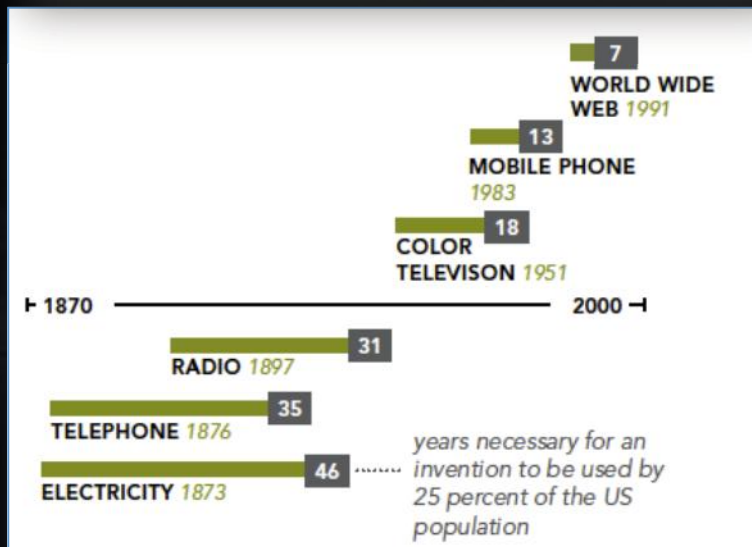
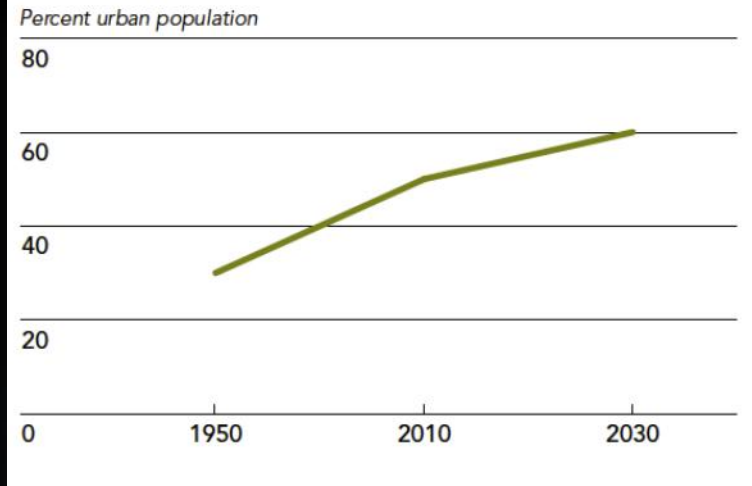
New realities challenge traditional approaches to strategic planning.





What do emerging global trends reveal?

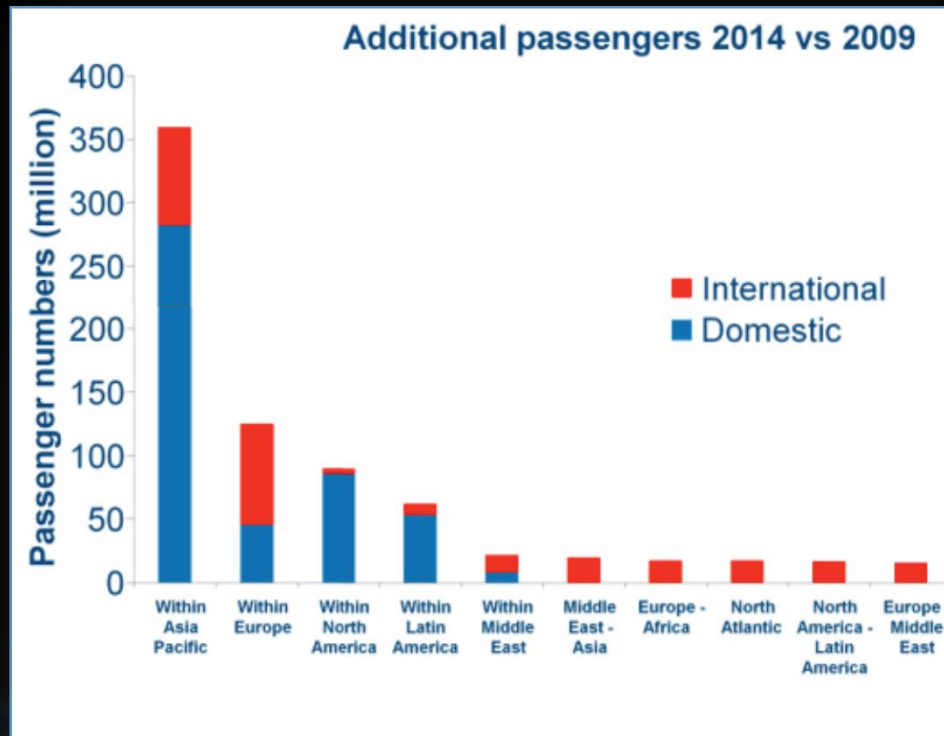
New realities challenge traditional approaches to strategic planning.



Source: National Intelligence Council



Why are these trends important?



They drive global demand for air travel...

They drive expanding competition for high-tech manufacturing...

They drive "leapfrog" adoption of new technology and infrastructure...

They drive resource use, costs, constraints, and impacts...

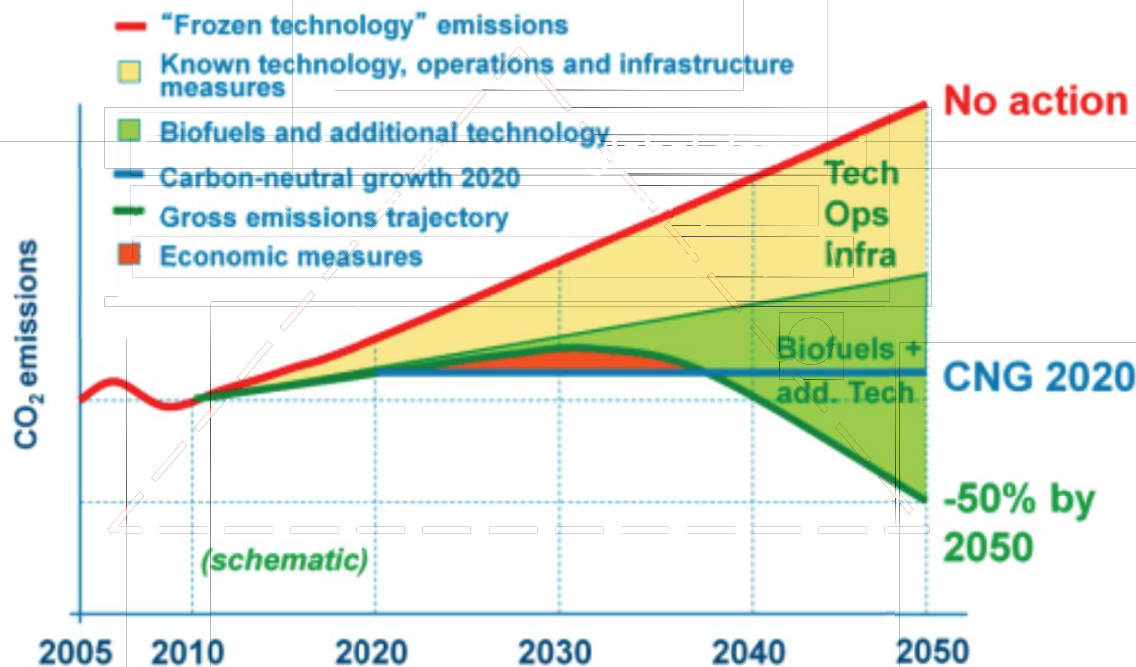
They drive the need for alternative energy technologies...



NASA Perspective: How do these trends affect aviation?

Three mega-drivers emerge

Emissions reduction roadmap



Severe energy and climate issues create enormous affordability and sustainability challenges.

Revolutions in automation, information, and communication technologies enable opportunity for safety-critical autonomous systems.



NASA Is Responding With Its Aeronautics Mission

NASA Aeronautics focuses on six strategic R&T thrusts



Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard



Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance



Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology



Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system



Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications





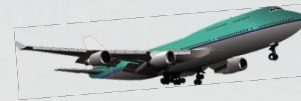
NASA Aeronautics Programs

Advanced Air
Vehicles
Program

Integrated
Aviation
Systems
Program

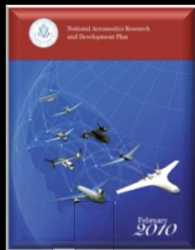
Airspace
Operations
and Safety
Program

Transformative
Aeronautics
Concept
Program





NASA Subsonic Transport System-Level Metrics



Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility



v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)	-33%	-50%	-60%

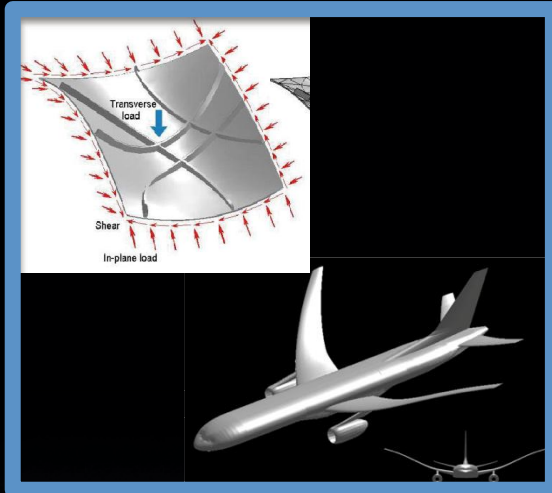
* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

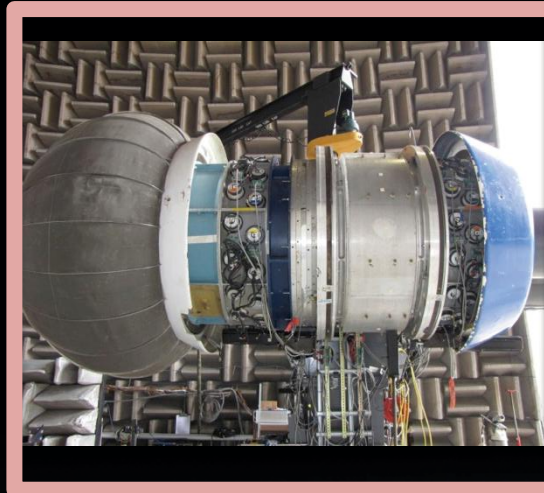
† CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

Research addressing revolutionary far-term goals with opportunities for near-term impact

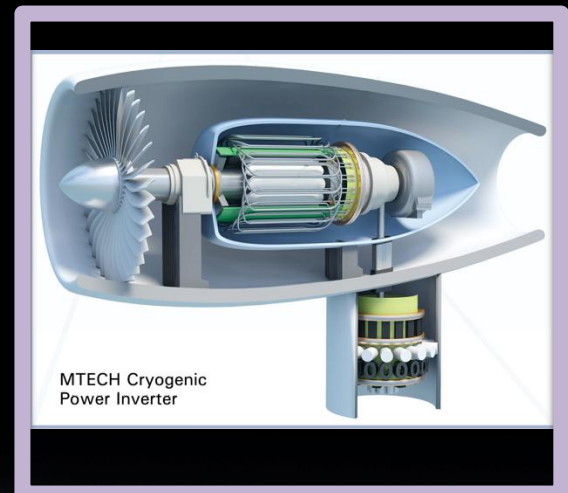
Research Themes



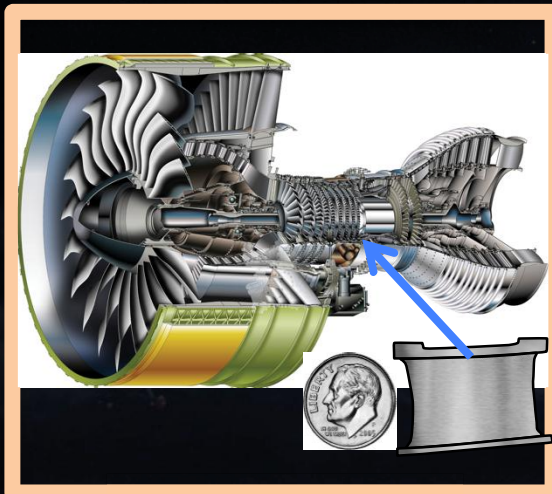
Lighter Weight
Fuselage and Wings



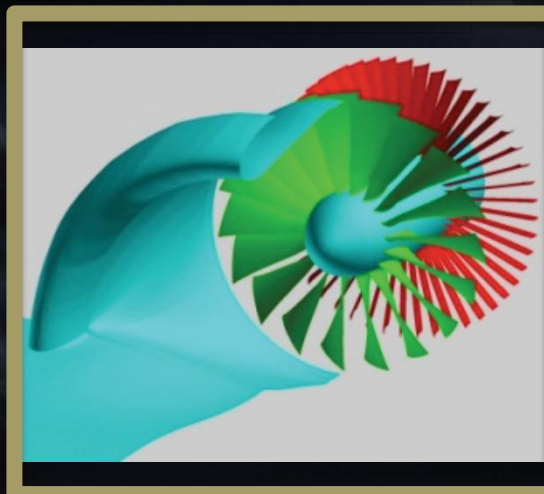
Noise Reduction
Technologies



Hybrid Gas Electric
Propulsion



Compact Higher
Bypass Propulsion



Propulsion Airframe
Integration

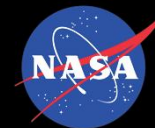


Alternative Fuels
Characterization



Electric Propulsion for Large Aircraft

- Why electric?
 - Fewer emissions (cleaner skies)
 - Less atmospheric heat release (less global warming)
 - Quieter flight (community and passenger comfort)
 - Better energy conservation (less dependence on fossil fuels)
 - More reliable systems (more efficiency and fewer delays)
- Considerable success in development of “all-electric” light GA aircraft and UAVs
- Creative ideas and technology advances needed to exploit full potential
- NASA can help accelerate key technologies in collaboration with OGAs, industry, and academia



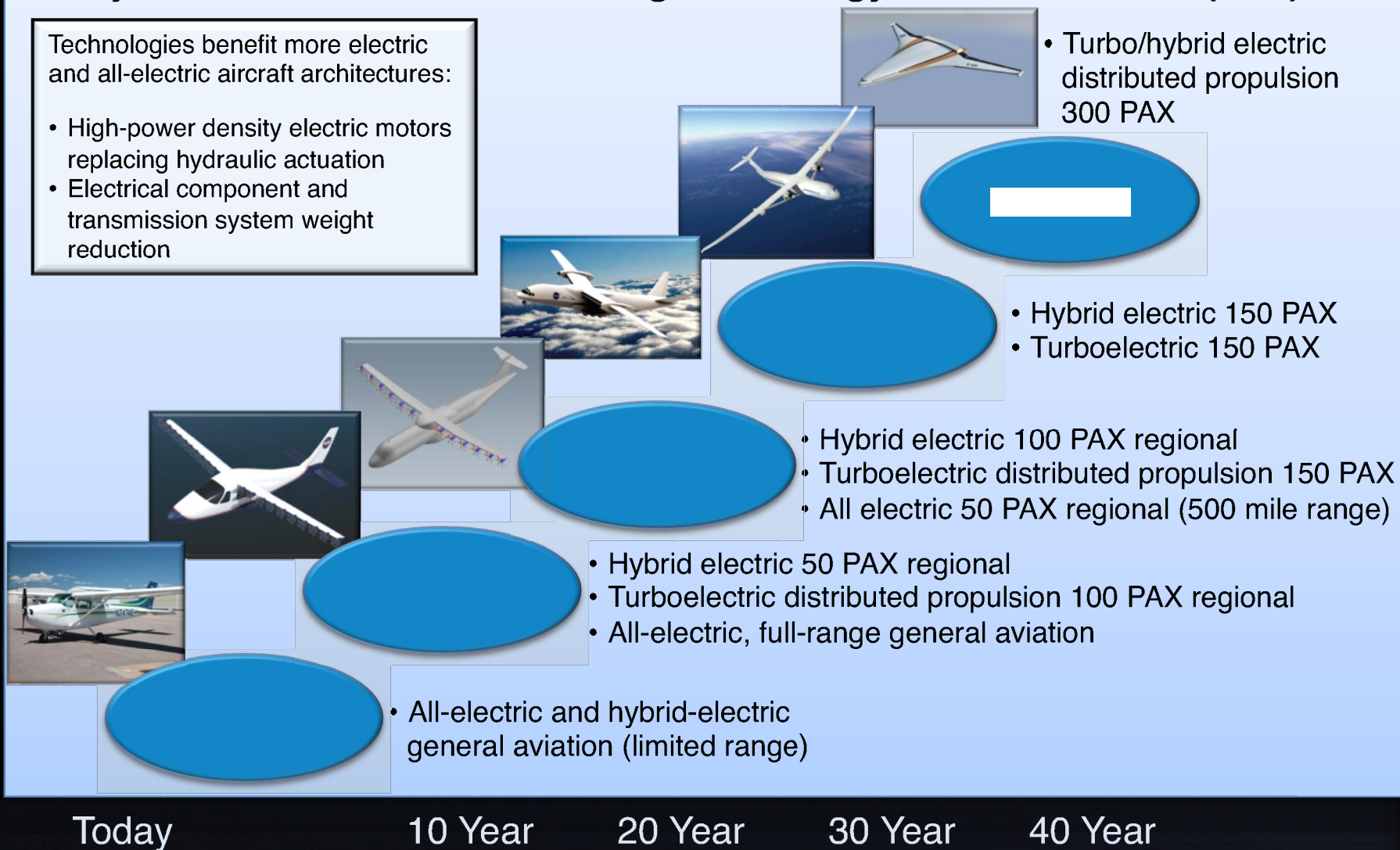
Aircraft Hybrid Electric Propulsion

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Power Level for Electrical Propulsion

Technologies benefit more electric and all-electric aircraft architectures:

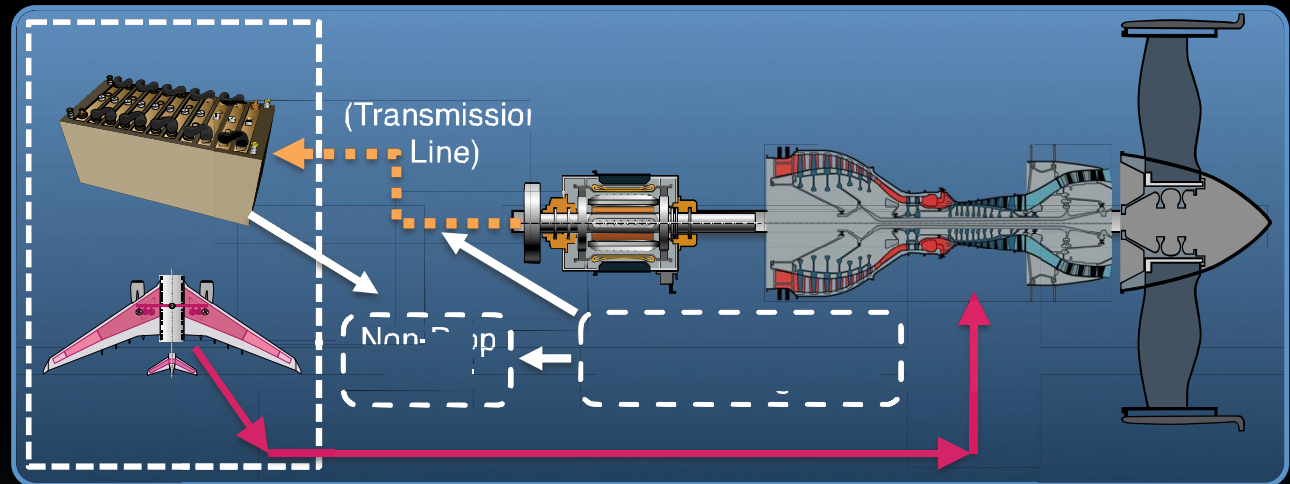
- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction





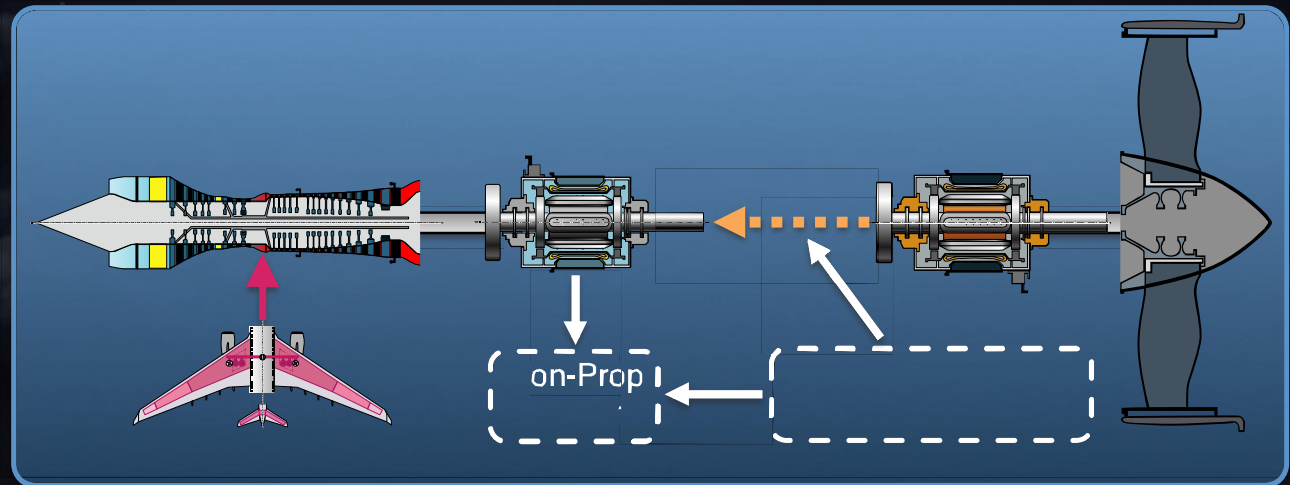
Possible Future Commercial Large Transport Aircraft

Hybrid Electric



Both concepts can use either non-cryogenic motors or cryogenic superconducting motors.

Turbo Electric





Estimated Benefits From Systems Studies

SUGAR (baseline Boeing 737–800)

- ~60% fuel burn reduction
- ~53% energy use reduction
- 77 to 87% reduction in NO_x
- 24-31 EPNdB cum noise reduction



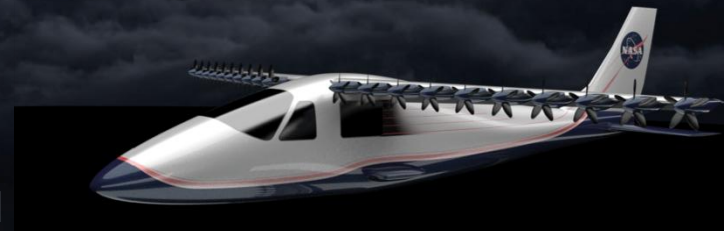
N3–X (baseline Boeing 777–200)

- ~63% energy use reduction
- ~90% NO_x reduction
- 32-64 EPNdB cum noise reduction

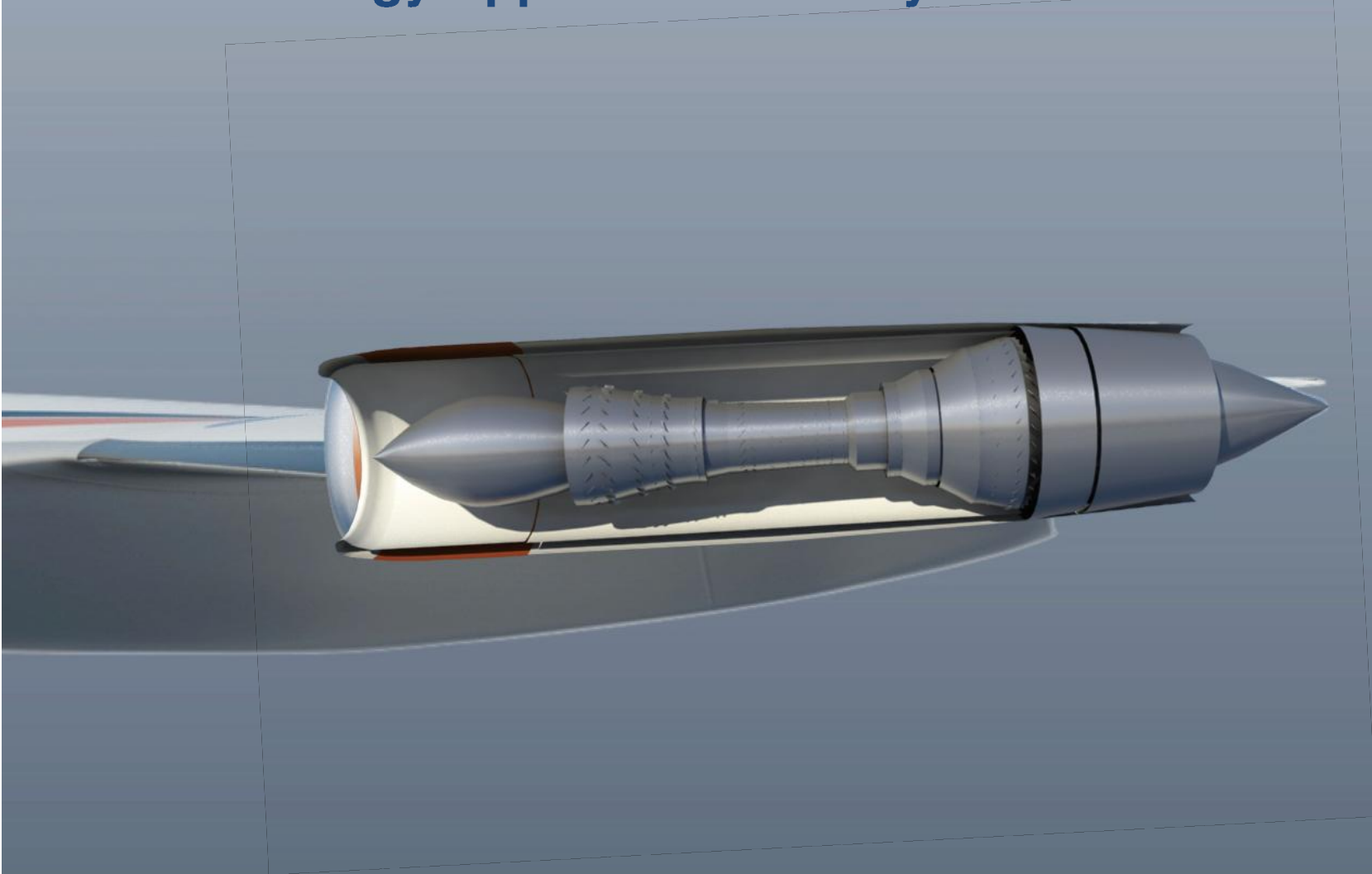


LEAPTech Wing Technology for GA (baseline Cirrus SR–22)

- 5 to 9x lower energy use/cost and emission
- 25 dB lower community noise
- Propulsion redundancy, improved ride quality, and control robustness



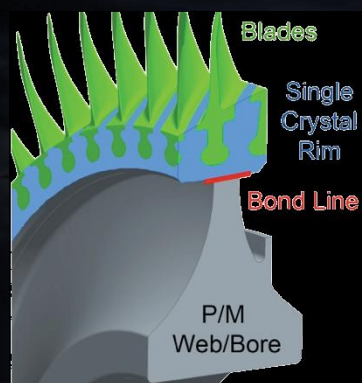
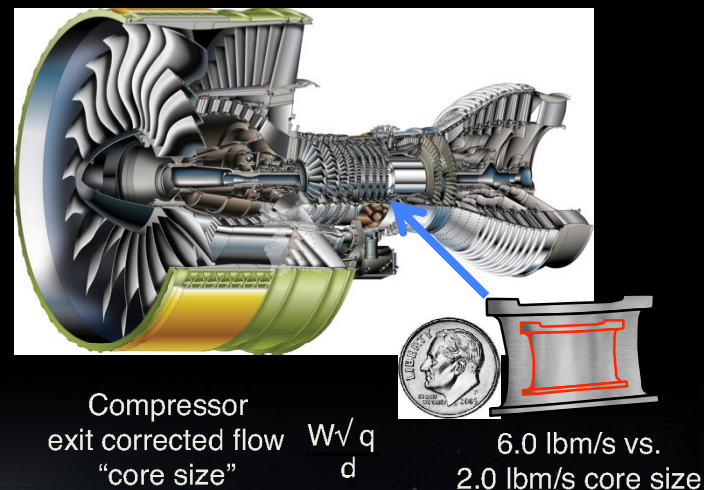
Technology Applications for Hybrid-Electric Vehicles





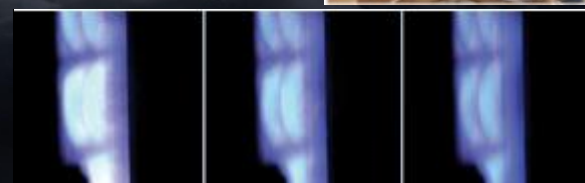
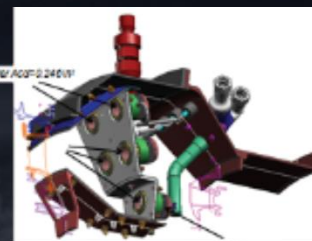
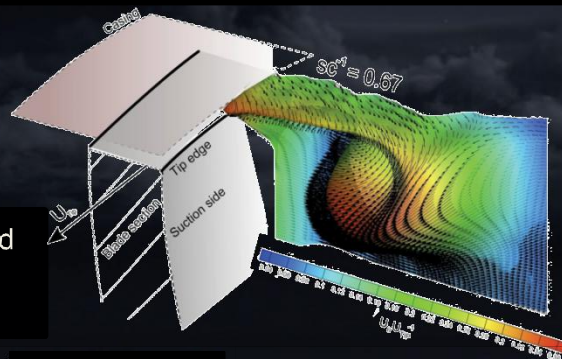
Highly Efficient Gas Generator

- 1500 °F capable disks, coatings, and noncontacting seals
- 2700 °F capable CMC turbine blades
- Low NOx fuel-flexible combustion
- Characterization of alternative fuels emissions
- Minimize losses due to large tip and hub seal cavity gaps of small size core
- Minimize cooling/leakage losses
- Assess system benefits and evaluate “smaller core” technology concepts for high-speed compressor demonstration

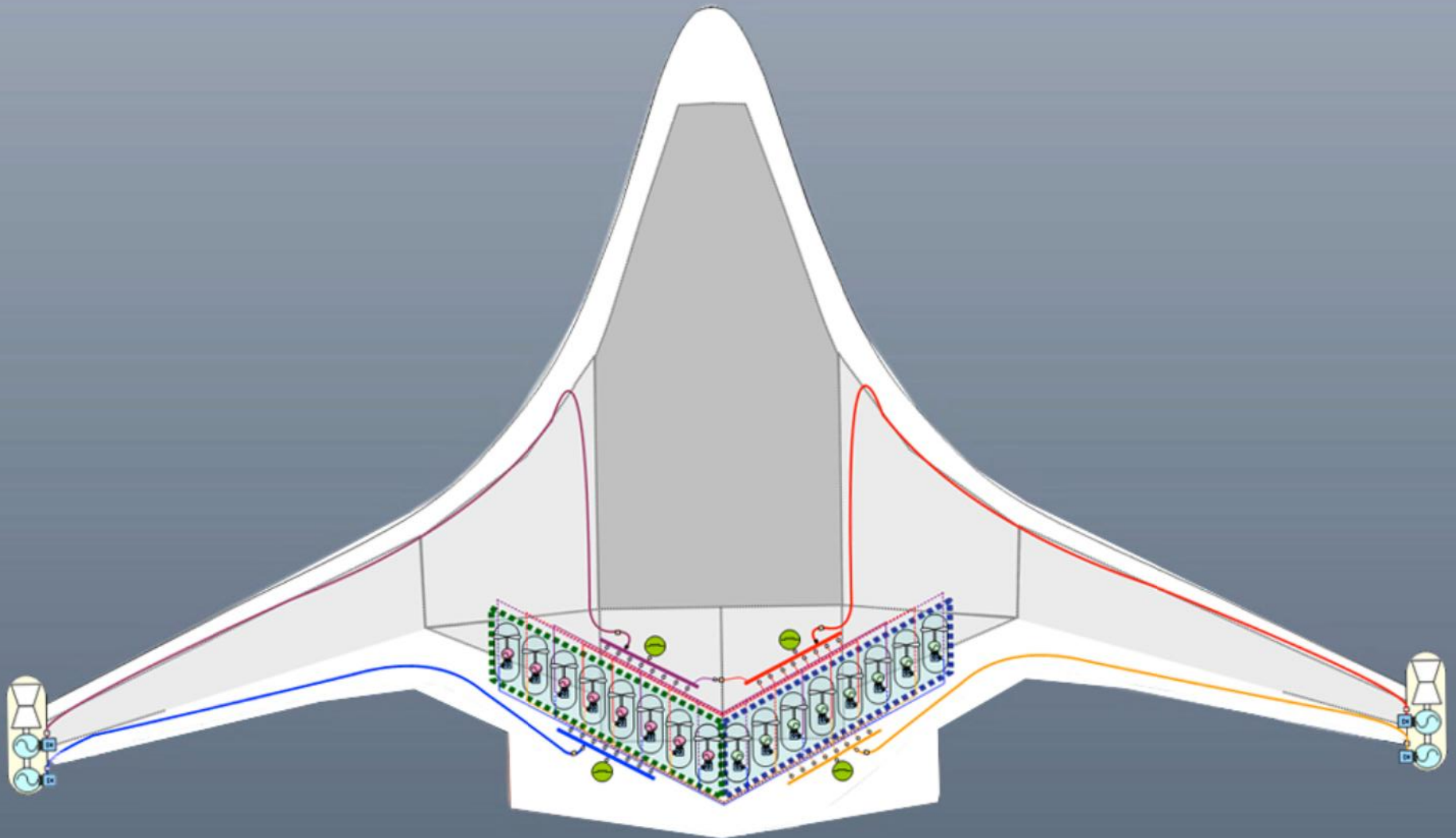


1500 F, bonded hybrid disk concept

Tip/endwall aerodynamic loss mitigation



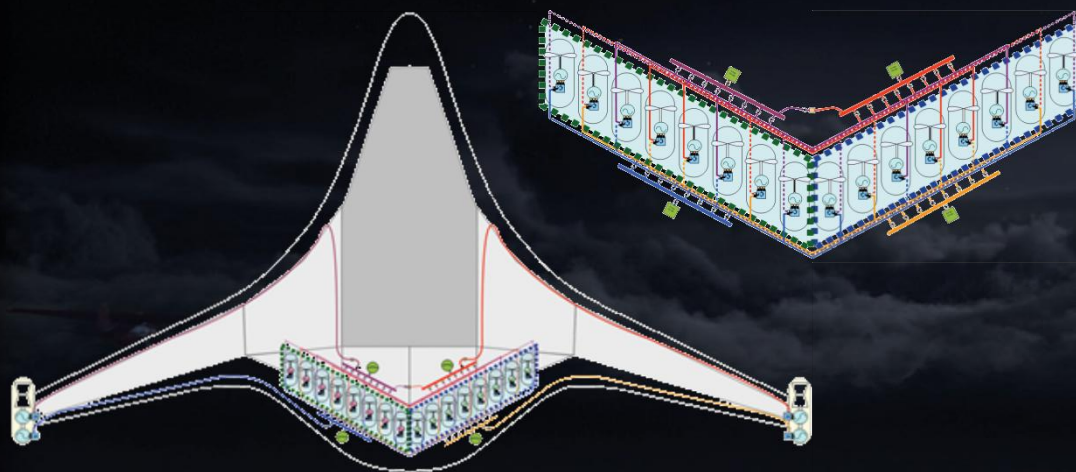
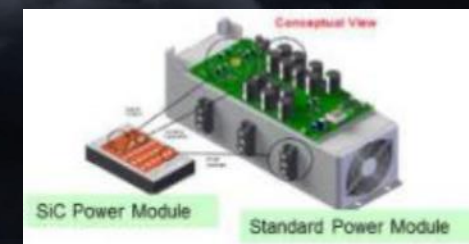
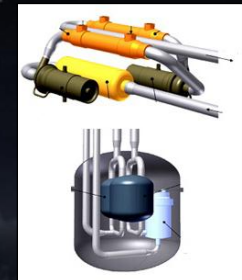
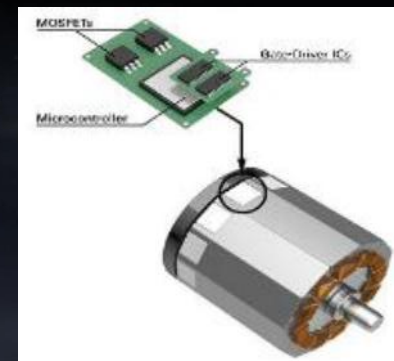
Technology Applications for Hybrid-Electric Vehicles





Power Systems Architectures

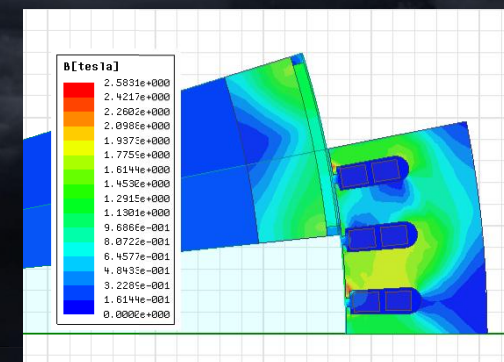
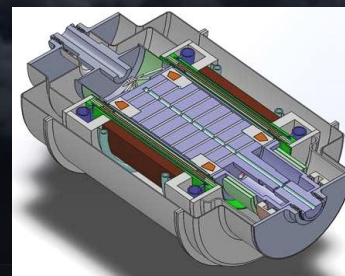
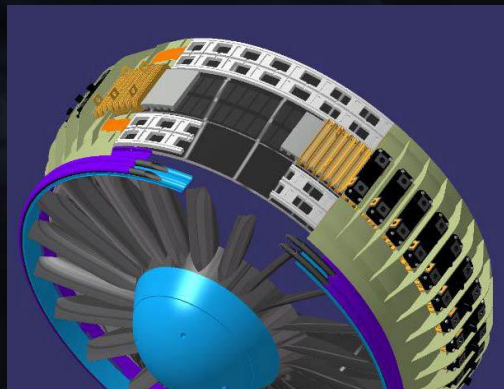
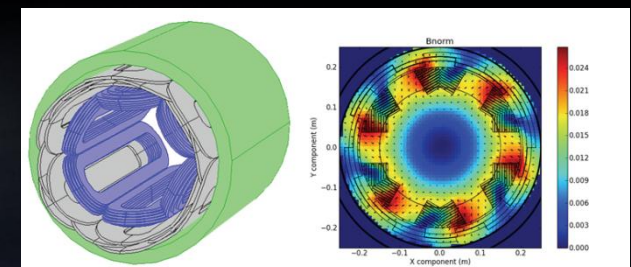
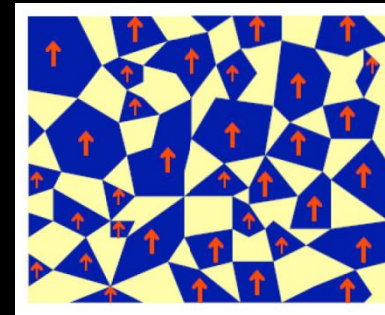
- Multikilovolt power system architecture and associated control system for transmission and use of multimegawatt power in aircraft
- Integrated thermal management and motor control schemes
- Enabling materials and manufacturing technologies



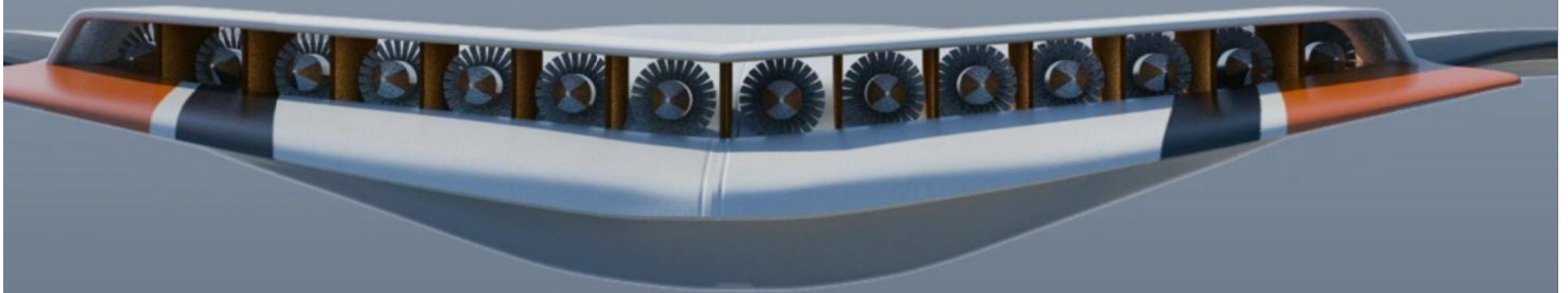


High-Power Density Motors

- Cryogenic, superconducting motors for long term
- Normal conductor motors for near and intermediate term
- High power to weight ratio is enabling
- Materials and manufacturing technologies advances required
- Design and test 1-MW noncryogenic electric motor starting in FY2015



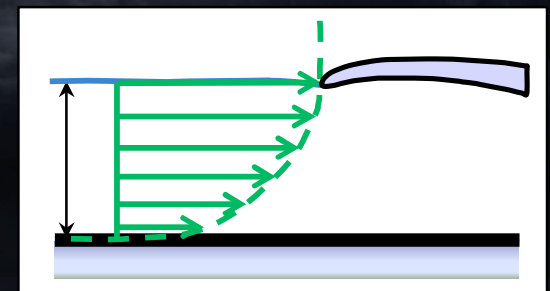
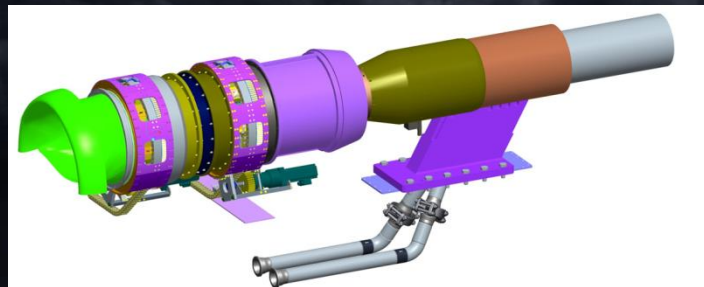
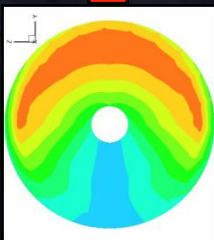
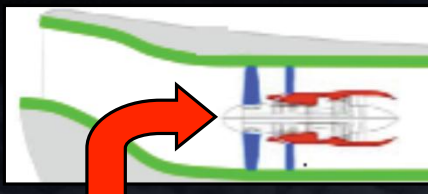
Technology Applications for Hybrid-Electric Vehicles





Understanding Boundary Layer Ingestion Systems

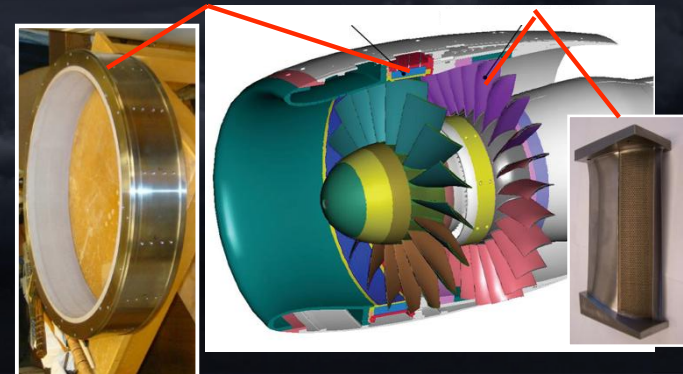
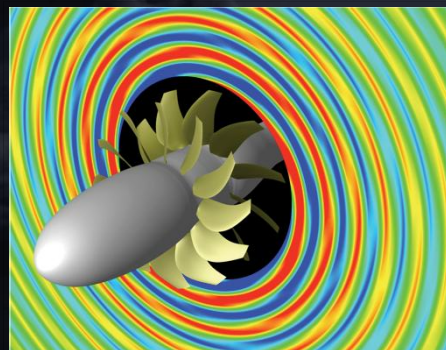
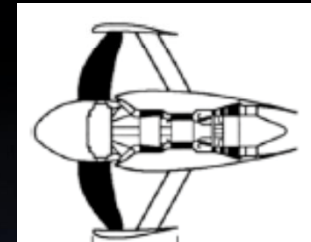
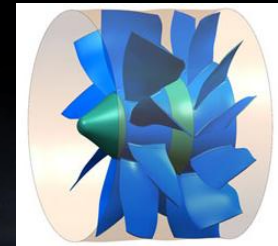
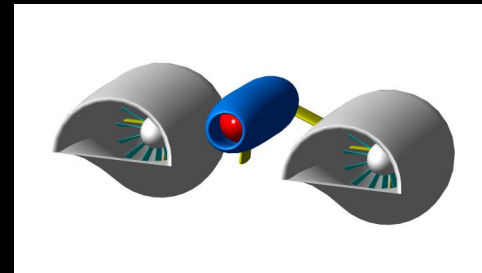
- Assess net system-level benefits of propulsion-airframe integration concepts relative to podded engines.
- Measure boundary layer ingestion benefits of integrated propulsion airframe configuration relative to podded engine.
- Design highly coupled inlet/fan tolerant to continuous operation in distorted inflow.
- Test performance of highly coupled inlet/fan design required to achieve net system level benefits.





Efficient, Low Noise Propulsor Systems

- Conceive and explore advanced propulsor architectures and technologies that alter the trajectory of noise and fuel burn trends for fans and open rotors to achieve future performance targets.
- Enhance analysis capabilities and acquire verification data to model nontraditional propulsion technologies and configurations.
- Maintain experimental facilities and capability to allow cutting-edge exploration of unique fan and open rotor system performance and associated physics.



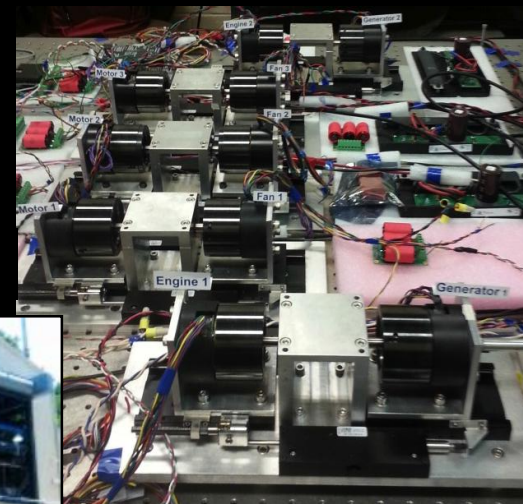
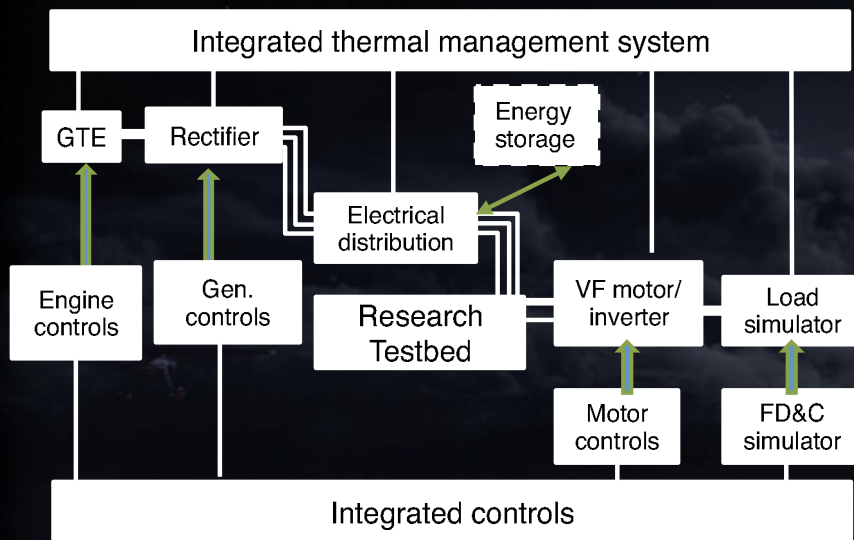
Technology Applications for Hybrid-Electric Vehicles





Enabling System Testing

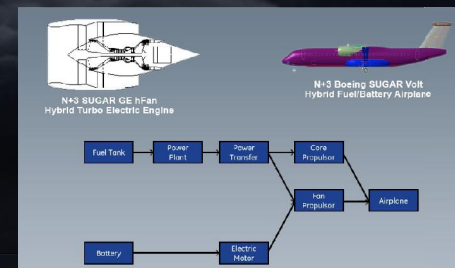
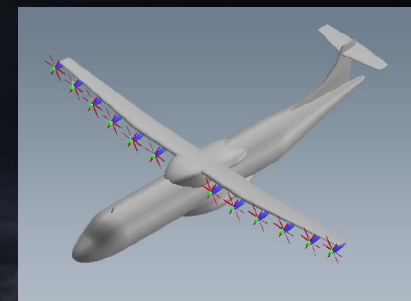
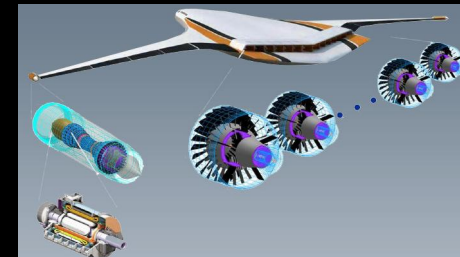
- Use system-level simulation capability to emerge requirements.
- Demonstrate technology at appropriate scale for best research value.
- Integrate power, controls, and thermal management into system testing.
- Validated tools and data that industry and future government projects can use for further development.





Integrated Vehicles and Concept Evaluations

- Determine design requirements and trade space for hybrid electric propulsion vehicles
- Identify near-term technologies that can benefit aircraft non-propulsive electric power
- Enhance analysis capabilities to model non-traditional vehicle configurations with HE systems
- Establish vehicle conceptual designs that span power requirements from GA (<1 MW) to regional jets (1-2 MW) to single-aisle transports (5-10 MW)





Looking to the future...

- Exciting challenges for an industry that was deemed “mature”
- Conceptual designs and trade studies for electric-based concepts
- Tech development and demonstration for N+3 MW class aircraft
- Development of core technologies, i.e., turbine coupled motors, propulsion modeling, power architecture, power electronics, thermal management and flight controls
- Multiplatform technology testbeds demonstrating
- Development of multiscale modeling and simulations tools
- Focus on future large regional jets and single aisle twin engine aircraft for greatest impact

